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Space Shuttle Phase B''
Final Report
Volume I. Executive Summary

Contract NAS9-10960
DRL T-751, Line Item 6
DRD SE-420T
SD 72-SH-0012-1
15 March 1972

Space Division • North American Rockwell 12214 Lakewood Boulevard, Downey, California 90241

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SPACE SHUTTLE
PHASE B'' FINAL REPORT
VOLUME I EXECUTIVE SUMMARY

Approved by

B. Hello
Vice President and Program Manager
Space Shuttle Program

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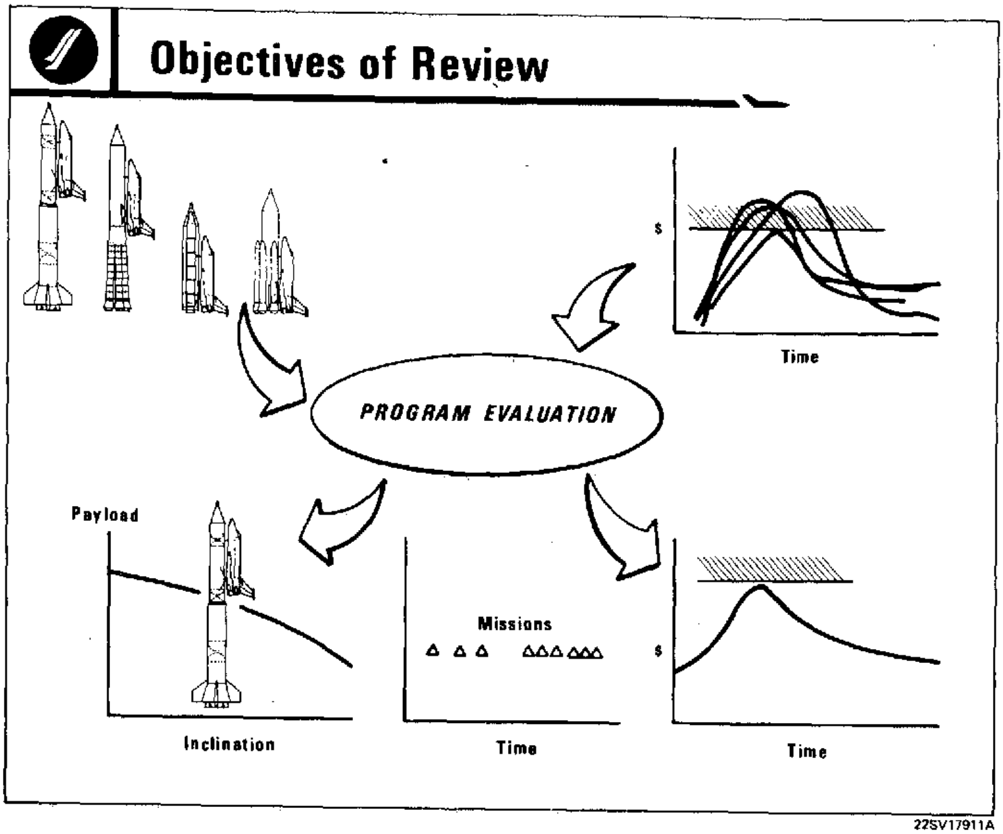
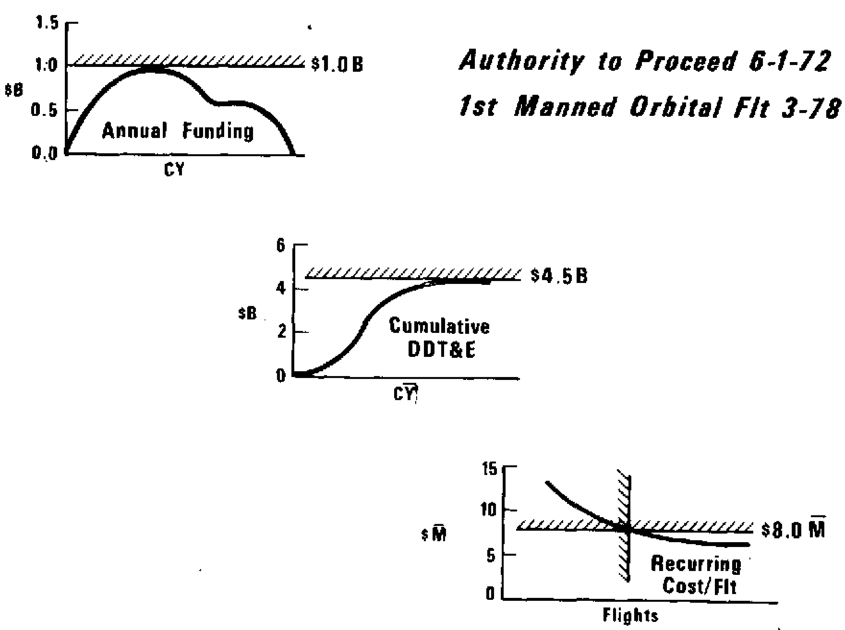


The objective of the Phase B'' study was to identify the differences among total system concepts with particular interest in those that lead to selection of a system that performs the missions within budget and schedule constraints. This summary presents the major results of the study and the resulting impact on selection of the best Space Shuttle system.

Program Schedule & Funding Constraints



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For a vehicle system program to be acceptable, it must pass three funding requirement gates: (1) one billion dollar maximum annual funding requirement, (2) a four and one-half billion cumulative design, development, test, and evaluation (DDT&E) cost exclusive of NASA requirements, and (3) a recurring cost per flight no greater than $8 million. It will be seen in the evaluation that no program satisfactorily met all of these gates. Those which typically had a low cumulative DDT&E or annual funding requirement generally exceeded the recurring cost per flight whereas those programs which exceeded the cumulative DDT&E or annual funding requirement generally met the recurring cost per flight requirement.

Technical Issues

ISSUE	*FINDINGS*
BOOSTER ISSUES	
• SRM TVC Requirements	
• Stage Separation	
• SRM Thrust Termination Requirements	
ABORT	
• Mode	
• Control	
• MPS Requirements	
ENVIRONMENT IMPACT	
TEST & FACILITY IMPACT	

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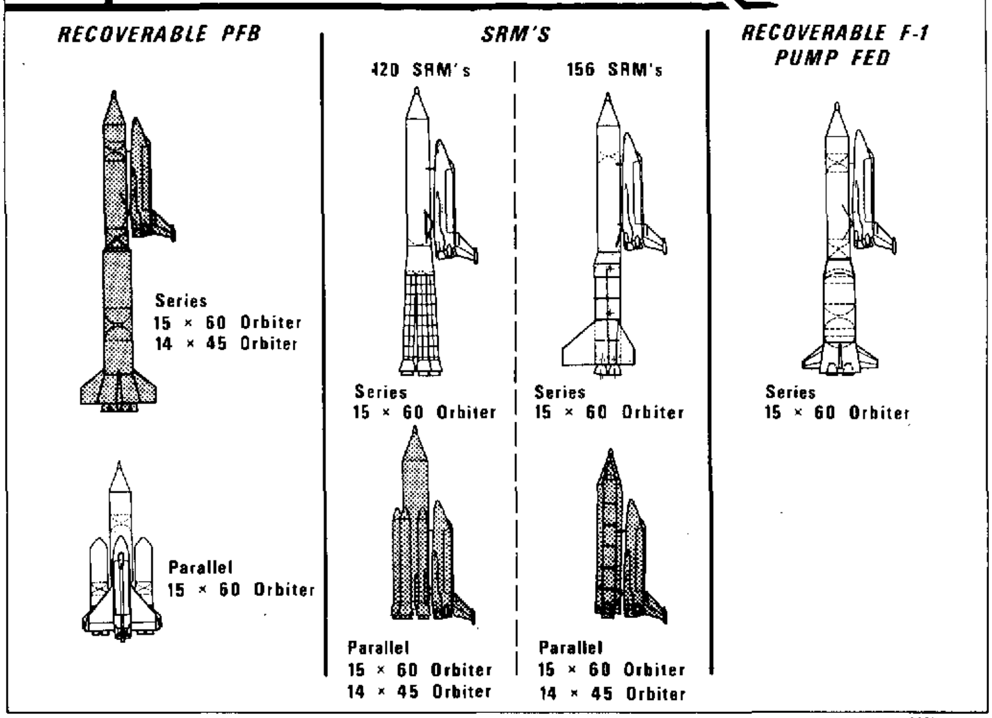
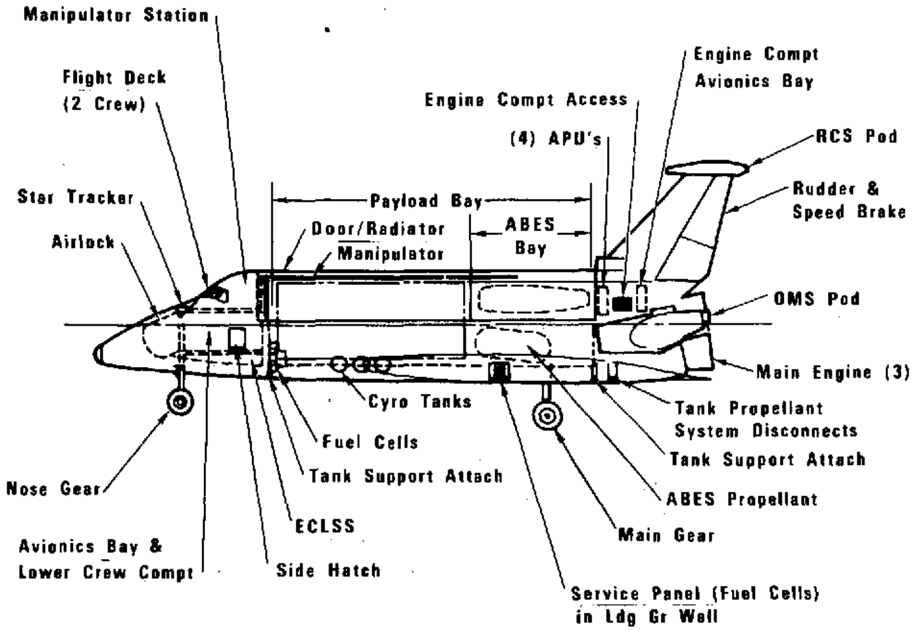
The key technical issues which will be discussed on the following pages are listed in the chart. Dynamic studies were completed to determine the thrust vector control requirements, separation modes, thrust termination requirements, and abort modes for both series- and parallel-burn systems and for both liquid and solid rocket motor boosters. The requirements for off-the-pad and in-flight abort were determined together with the main propulsion system requirements to assure elimination of the downrange landing requirement. Finally, an evaluation of the relative test and facility requirements for liquid-fed versus solid-propellant motor boost systems was determined, and the impact of the solid rocket motor impact on the vehicle and ground environment was determined.

Study Matrix



The spectrum of launch configurations analyzed in this study period is described on the chart. Emphasis was placed on three systems: the recoverable pressure-fed booster system in a series-burn mode and two parallel-burn systems, the first using 120-inch-diameter solid rocket motors and the second using 156-inch-diameter solid rocket motors. In each case, two orbiter systems were analyzed: a 15-foot-diameter by 60-foot-long cargo bay orbiter and a 14-foot-diameter by 45-foot-long cargo bay orbiter.

Inboard Profile



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The inboard profile drawing illustrates the interior arrangement of the major subsystems. Highlights of the propulsion system shown are all propellant tank disconnects mounted aft. The orbit-maneuvering-system pods are on opposite sides of the aft fuselage, wing-tip- and vertical-tail-located reaction-control-system pods, and the three-engine main-propulsion system. Shown in phantom in the payload bay is the air-breathing engine system kit. The payload bay features manipulators located in a fairing and radiators mounted on the payload bay doors. The crew and passenger station has a forward-mounted air lock and lower avionics bay and crew compartment. A side hatch provides for rapid egress.

Flight Control Evaluation

	Alternate Configurations	Control Options
Series	PFB	Booster TVC
Parallel	120 In. SRM	Orbiter TVC
	156 In. SRM	Aerosurfaces
		Fin

Issue:
- Is Booster TVC Required

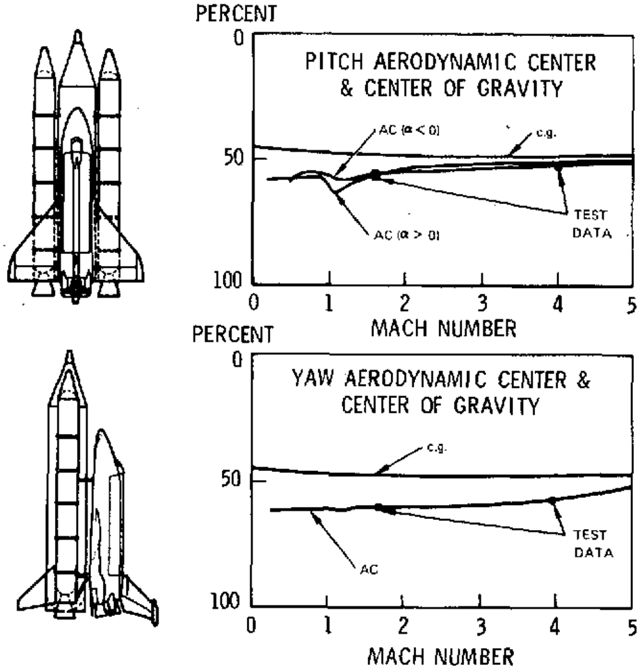
Requirements:
- Load $q\beta = 2400$ $q\alpha = 2800$
- Roll Control < 30° With Winds
- Minimize Sum of Structural and Propellant Weight

Considerations:
- c.g. Travel
- Winds/Gusts
- Thrust Misalign/Mismatch
- Orb Engine Out
- Actuator Failure

22SV179278

The key issues in the flight control studies were to verify the control requirements for the pressure-fed series-burn system and to determine the most appropriate control mode for the parallel-burn systems, and in particular to determine whether or not thrust vector control was required on the parallel-burn booster motors. In these analyses load limits as illustrated on the chart and roll limits with winds were imposed on the system. Tradeoffs were made to minimize the sum of the structural penalty and the additional propellant weight required to compensate for dispersions. The analyses considered the requirements to track c. g., to control through winds and gusts, to compensate for thrust misalignments and thrust level mismatches, to provide adequate control with one orbiter engine out or with one actuator failure on any system. The chart illustrates the considerations in analyzing the control requirements for the pressure-fed booster.

Stability Characteristics
156 in. SRM Parallel Launch Config



- WIND TUNNEL RESULTS CONFIRM ESTIMATES
- PITCH & YAW STABILITY OVER MACH RANGE
- ASYMMETRIC CONFIG PRODUCES DUAL PITCH AC'S - F/C REQMT SET BY POSITIVE α'S

DATA BASE: GDHSWT
TEST NO. 326-0

22SV18085B

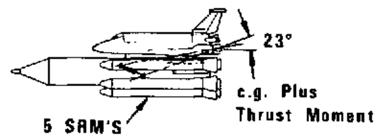
Wind tunnel results from GDHSWT Test No. 326-0 are presented at Mach numbers 1.62 and 4.0 as substantiating evidence of pitch and yaw aerodynamic center predictions over the Mach range for the present 156-inch solid rocket motor configuration. It is evident from both the predicted data and the test results shown that static stability is achieved over the boost Mach range.

Vehicle asymmetry results in separate pitch AC curves for positive and negative angles of attack. Both the predicted data, which was based on modifications to MDAC Wind Tunnel Test No. S-222 results for a similar configuration, and the substantiating data points from the GDHSWT test exhibited considerable nonlinearity in the pitching moment and normal force coefficients in the region near zero angle of attack. However, it was possible to obtain a reasonable representation of the test data for both configurations by considering two linear ranges, one for $\alpha > 0$ and the other for $\alpha < 0$. Only one yaw AC curve is required due to configuration symmetry about the X-Z plane.

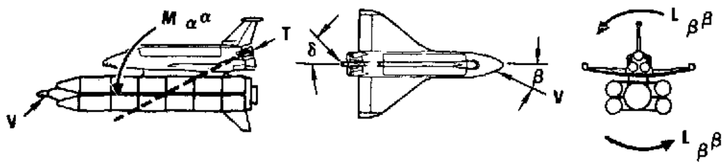
120 in. SRM Roll/Yaw Control

Pitch
- 5 SRMS - Orbiter TVC Inadequate
- 4 SRMS - Orbiter TVC Marginal

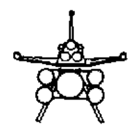
Roll
- Orbiter TVC Insufficient Authority



Orbiter TVC & Aero Surface Control
- Increased Hinge Moments × 3
- Hydraulic System Impact



Orbiter TVC & Aero Surface Control & Ventral Fins
- Separation Problems
- Hydraulic System Impact



Booster TVC
- Acceptable Control

Booster "Trim" TVC & Orbiter TVC & Aero Surface Control
- Hydraulic System Impact

22SV182008

Dynamic analyses immediately illustrated that the orbiter thrust vector control (TVC) was not capable of controlling roll. Supplementing the orbiter thrust vector control with orbiter aerosurface control within the current hinge moment limitations resulted in a roll displacement greater than 100 degrees and rates up to 20 degrees per second. To decrease the roll displacement and rate to a reasonable value, the hinge moment increases by at least a factor of 3.

An alternate concept involving the use of ventral fins indicates that acceptable control is possible with the current hinge moments. However, there was a significant weight impact because of the addition of the fins, an impact on the hydraulic system because of the requirement to actuate the aerodynamic surfaces and the orbiter TVC simultaneously, and finally an added complexity to the separation problem because of the presence of the fins on the separating 120-inch booster motors.

The option where the only control mode would be booster TVC was determined to be an acceptable control system without orbiter impact.

A last option investigated included the use of booster thrust vector control to provide trim only. The orbiter TVC and aerosurfaces would provide control for disturbances. In this system, a simple blow-down hydraulic system was assumed. Again, because of the use of orbiter TVC and aerosurface control simultaneously, there would be an impact on the orbiter hydraulic system. This last system would be more involved and risky than the booster TVC-only system, although perhaps less costly. This particular trade study was performed on the 156-inch solid rocket motor parallel-burn system but the results are felt to be also applicable to the 120-inch solid rocket motors. Therefore, TVC on the booster only is recommended for this system.

Booster Control Option Trades-156 In. SRM

	Weight Δ (Lb)			Program Cost Δ ($ × 10^{-6})			
	Orbiter	Booster	Fins	Orbiter	Booster	Fins	Total
Booster TVC δ = ±5°, $\dot{\delta}$ = 5°/Sec		16,000			116		116 ✓
Orbiter TVC + Aerosurface + Fins (Nominal Hinge Moments)	1,690		8,000	28		296	324
Orbiter TVC + Aerosurfaces (3 × Hinge Moments)	14,000			225			225
Orbiter TVC + Aerosurfaces + "Slow" Booster Trim in Pitch δ = ±3°, $\dot{\delta}$ = 0.1 Deg/Sec	1,690	1,200		28	58		86*

*Complex Control Blending

22SV18121B

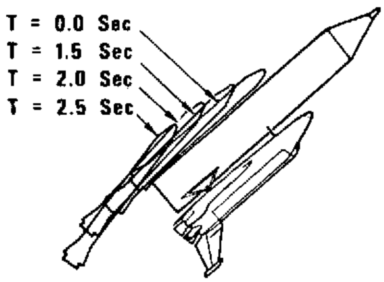
A trade study was completed to determine the program cost impact of various modes of control for the 156-inch solid rocket motor parallel-burn system. These are illustrated on the chart. It is seen that the cheapest system in terms of program impact is the orbiter thrust vector control plus aerosurfaces for disturbance control with a slow booster trim in pitch where the program impact was 86 million dollars. However, because of the relative complexity of blending the three different control modes, it was recommended booster thrust vector control only with deflections up to 5 degrees at rates of 5 degrees per second be utilized for the parallel-burn systems (156-inch as well as 120-inch).

120 in. SRM Orbiter-Tank/SRM Separation

Concept-Hinged Links

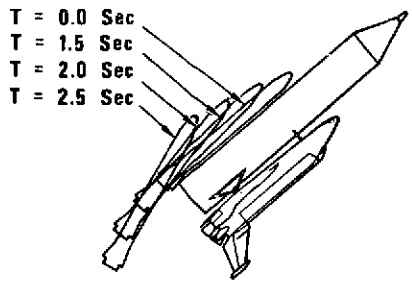
MAX $\bar{Q}$ SEPARATION

$\bar{Q}$ = 650 PSF
α = 0



NOMINAL STAGING

$\bar{Q}$ = 56 PSF
α = 0



Propulsion Characteristics at Separation

- Orb MPS: Full Thrust
- 120 in. SRM: 54K Each (Abort)
- Abort SRM: 134.5K Each

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The trajectory of a pitch plane 120-inch solid rocket motor during separation sequences at max $\bar{q}$ and at nominal staging is shown. The orbiter main propulsion system is brought up to full thrust before starting separation.

The chart illustrates the concept studied for separating the 120-inch solid rocket motors as well as the 156-inch solid rocket motors. In this concept, hinged links fore and aft which provide separation as the links go into tension are used to assure positive displacement of the solid motors. The length of the hinges is adjusted to provide positive separation and simultaneous release of all links from the motors. The same system is used for the motor mounted in the pitch plane and those mounted on the sides of the external oxygen-hydrogen tank.

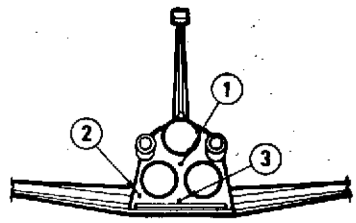
Booster/orbiter separation of the tandem configuration pressure-fed booster is similar to the dual-plane separation of the Saturn S-II stage.

Effect of SRM on Orbiter Base Heat Shield

Maximum Ascent Temperatures (F)

	1	2	3
PFB	700	620	700
120 in.	1070	1310	700
156 in.	1020	1220	700

- **Present Design Not Impacted by Increased Temperatures**



Increased Base Heating From SRM Plume Radiation

Base Heat Shield Δ Weight	
PFB	0
120 in.	40 Lb
156 in.	30 Lb

- ***NEGLIGIBLE DESIGN IMPACT***

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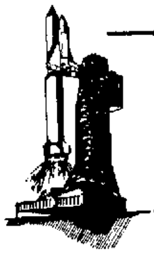
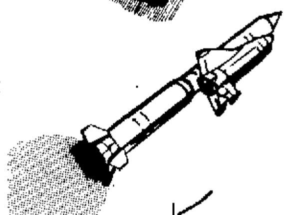
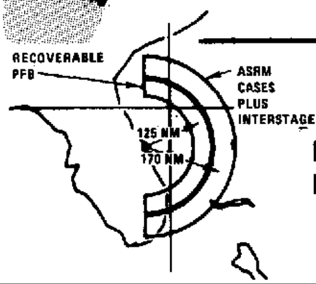
Heat shield weights for all three systems were computed. It is seen that almost negligible additional heat shield weight is required to compensate for the radiation from the solid rocket motor plumes because the design environment arises during entry, not ascent.

Environmental Effects



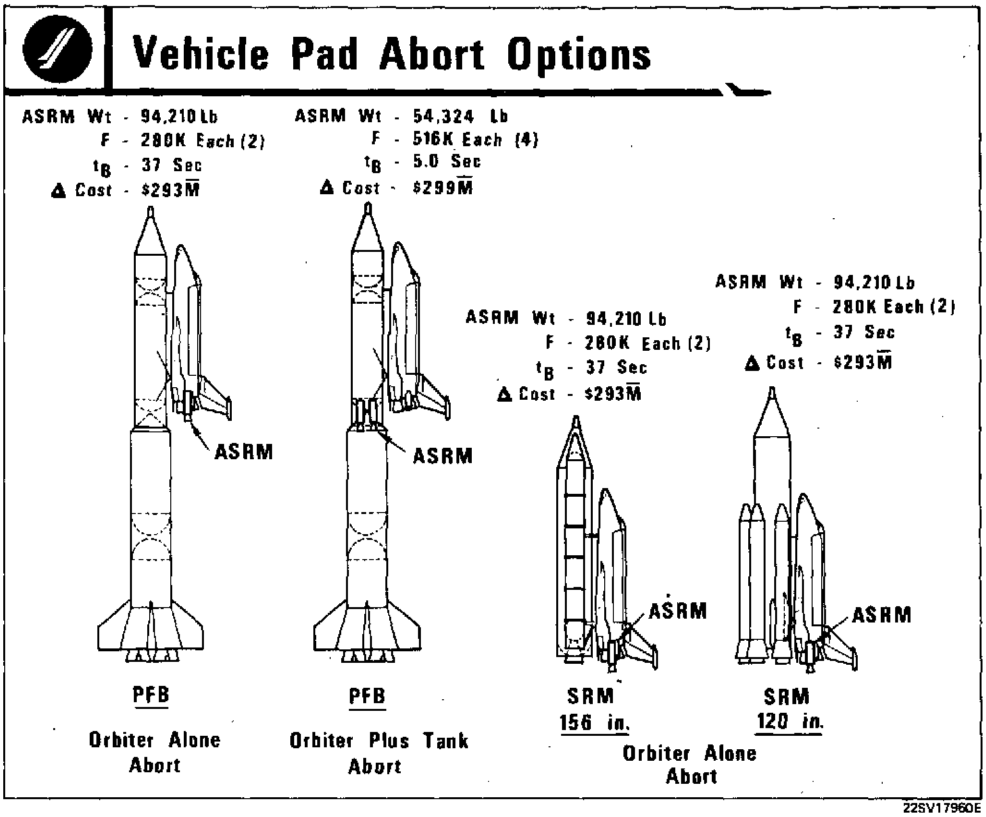




NOISE	**Less Than Saturn V** **112 db in Titusville**
POLLUTION	**Nominal Launch** **Less Than Federal Guidlines for Continuous Exposure** **Abort** **Exceeds Guidline by 15%**
BOOSTER FALL OUT	**Potential 180° Azimuth Launch**

22SV18076

The impact of the induced environment on the vehicle and on the area surrounding the launch pad was studied. The results indicated that the environment on the vehicle was acceptable for all systems although base heating and rocket exhaust noise levels were higher for the parallel systems, as expected. The chart summarizes the effects on the surrounding environment and, again, all systems are comparable.



Two options were available to provide for safe abort of the orbiter. In one case abort solid rocket motors are mounted on the aft portion of the orbiter fuselage as illustrated on the chart. This solution is appropriate for either a series-burn configuration or for the parallel-burn configurations. A second option incorporates abort solid rocket motors on the interstage between the external oxygen-hydrogen tank (EOHT) and a series-burn booster such as the pressure-fed booster. This option is only appropriate for a series-burn system because both the orbiter and the external oxygen-hydrogen tank abort from the booster. In a parallel system it would not be feasible to fly the orbiter and EOHT out from in between the cluster of solid rocket motors, and the size of the EOHT would require extremely large abort solid rocket motors (ASRM's).
It has been determined that the weight penalty imposed on the ASRM system is offset by the performance gained through the use of the abort system during the nominal mission. Specifically, after nominal staging the abort motors are ignited and fire in parallel with the orbiter motors. Careful sequencing of the ASRM firing is required together with possible throttling of the orbiter main propulsion system to avoid overacceleration of the orbiter.

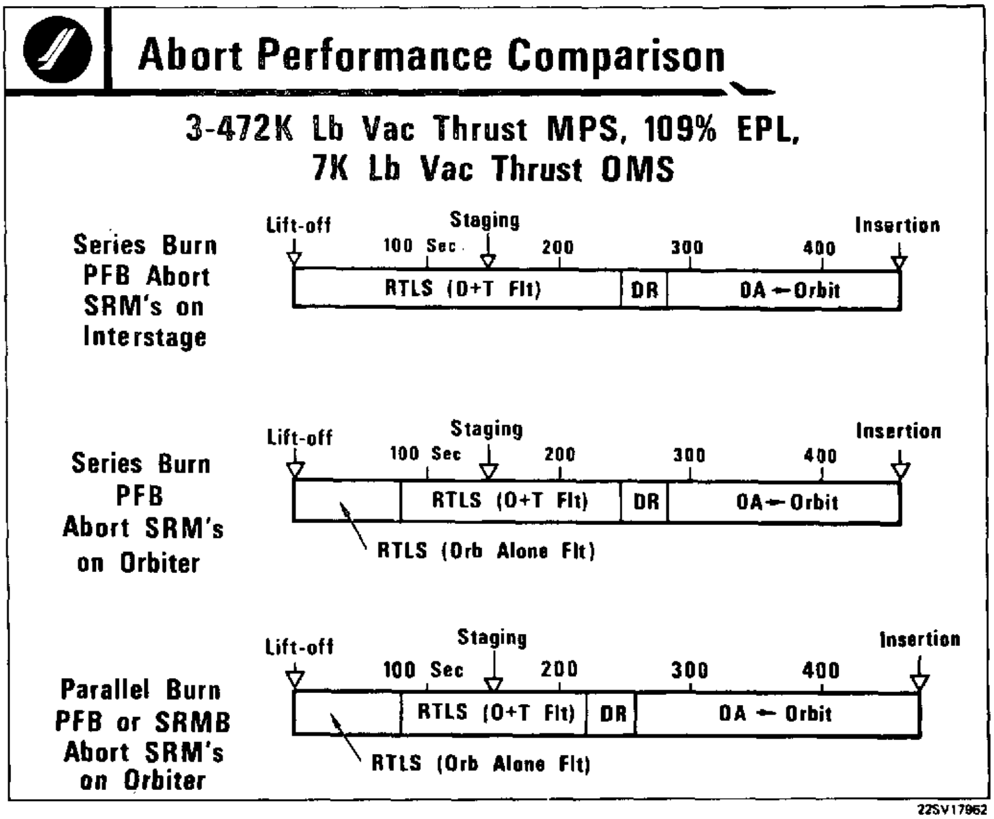
Cost estimates for these abort systems have been developed. In either case, the total system cost would be approximately $300 million.

Abort System

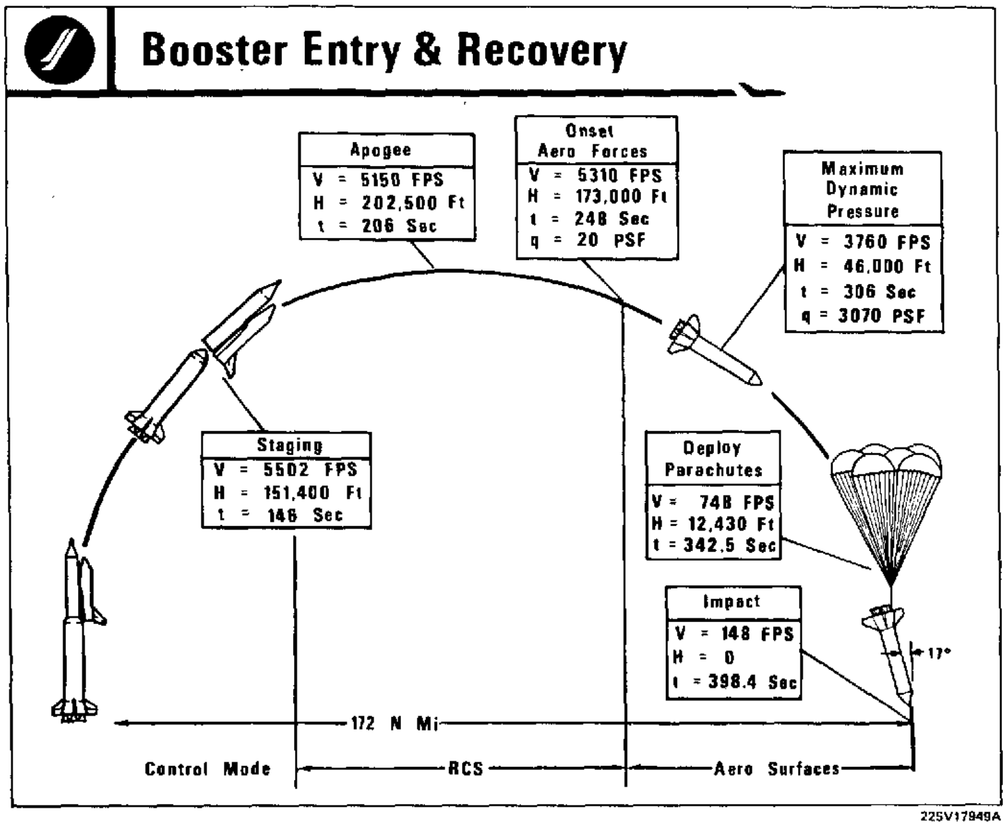
Time	ASRM's on Orbiter	ASRM's on Interstage
Pad 99% Wind ±1/4° Thrust Misalignment	• Rotate Launch Vehicle on Pad (PFB) • Precant Launch Vehicle for Clearance 2.5 Deg • ±3° TVC on ASRM for Initial Control • Aero Surface Control Adequate After 15 Sec	• Precant Thrust 2 Deg • SSME TVC After 4 Sec
Max Q	T< 80 Sec: Abort Orbiter Only, Control with Aero Surfaces T>80 Sec: Abort Orbiter & EOHT, Realign ASRM Thrust Through c.g. Control with SSME TVC	• Aero Stable - Ignite ASRM's for Separation, SSME TVC for Control
Staging	• Realign Thrust Vector Thru C.G. • Baseline Dual Plane Separation • Drop Interstage at 10 Sec • SRM Burn at 12 Sec After Separation	• Ignite ASRM's at Staging • Baseline Dual Plane Separation Sequence

22SV17923C

Each of the two options described previously impose control requirements on the vehicle and on the abort solid rocket motor (ASRM) system. The chart illustrates the control requirement for each of the most significant time sequences, that is, separation off the pad, max $\bar{q}$, and at nominal staging. The most significant difference between the two options is that in option 1 ASRM's on the orbiter require thrust vector control (TVC) for the ASRM's during the off-the-pad launch. Because the configuration is aerodynamically-stable and the aerosurfaces are effective at max $\bar{q}$, the TVC on the ASRM's is not required because the aero-surfaces are adequate. After 80 seconds of flight, the orbiter cannot return to the launch pad and must be separated with the external oxygen-hydrogen tank (EOHT). Because of the difference of location with the configuration center of gravity, the abort solid rocket motors must be repositioned to permit the thrust vector to pass through the configuration center of gravity. Space shuttle main engine (SSME) thrust vector control is then adequate for control during this period of time. The same requirements described persist at nominal staging. In the second option, the ASRM's on the interstage, no thrust control vector or reorientation of the ASRM's thrust vector is required at any time. Immediately (t = 3 sec) after liftoff, the SSME thrust vector control becomes effective and provides flight control. The control mode is similar to this option at max $\bar{q}$ and at nominal staging as well.



All the configurations have essentially the same abort performance in that all have the capability to return to the launch site up to staging. At staging, with consideration of one engine out, all configurations also have the capability to return to the launch site up to approximately 250 seconds for the series-burn systems and to approximately 210 seconds for any parallel-burn systems. At this point in the sequence, there is a gap where the vehicle cannot return to the launch site nor can it be injected into a once-around return orbit. Thus, a downrange landing requirements persists. After this gap, all configurations can be inserted into a trajectory that will take them once around to the launch site, or into a degraded mission capability orbit. It is noted that this performance is for a 472,000 vacuum thrust orbiter main propulsion system with a 109 percent emergency power level and an orbital maneuvering subsystem thrust level of 7000.



The primary booster issues are defined in four basic areas and are:

1. Pressure-fed engine and system development

    Weight and I_{sp}
    Combustion stability
    Pressurization

2. Entry techniques and requirements

    Stability and control

3. Recovery

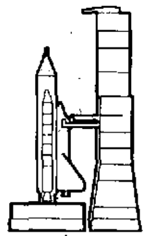
    Drag level (body and flaps)
    Chute deployment
    Impact loads

4. Retrieval and Refurbishment

    Turnaround time/spares

The mission profile defines the critical elements of the flight from launch, to staging, apogee, maximum dynamic pressure, deployment, and impact. The chart illustrates the mission profile elements and related issues.

Booster Cost Comparison Summary



Facilities
- Test
- Operations

Manpower
- Test
- Activation
- Operations

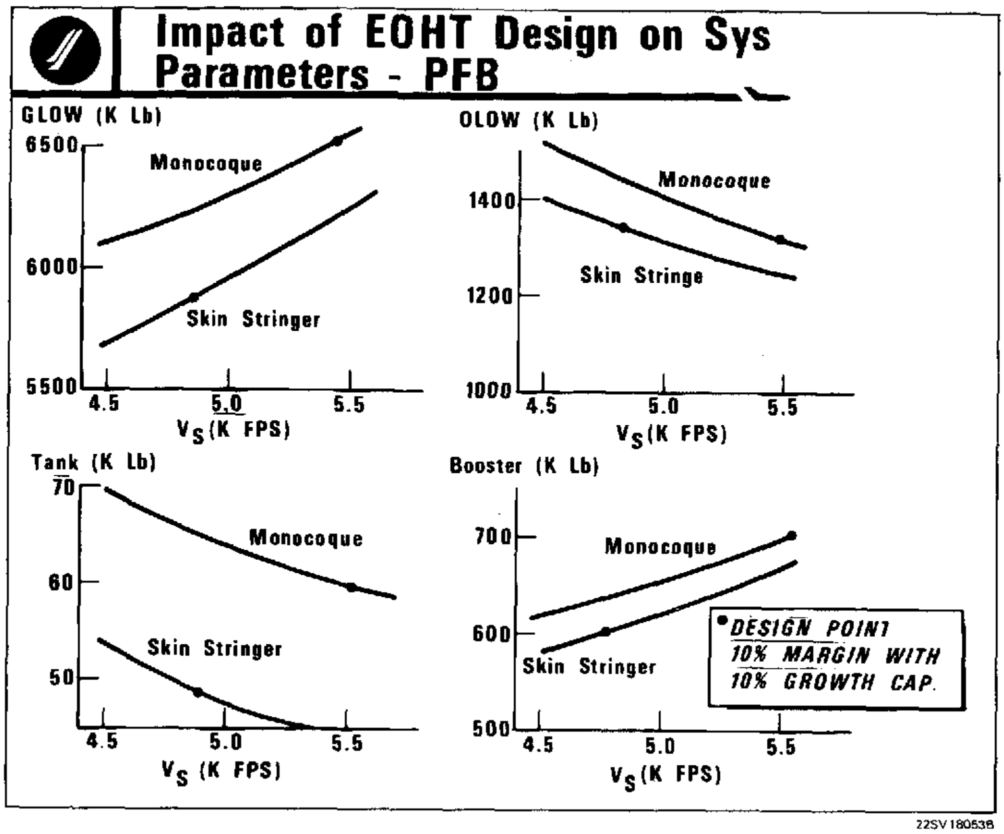
Support Equip.
- Test
- Operations

Logis & Maint
- Spares
- Transportation
- Fluids & Gases

	PFB	120 in.	156 in.
Total End Items/Support EQT	484	193	155
Total Man Months	64,060	35.233	28.827
DDT&E MM	27,096	14.903	12.195
Δ Facilities Cost Total	0 (Base)	-429.54M	-549.24M

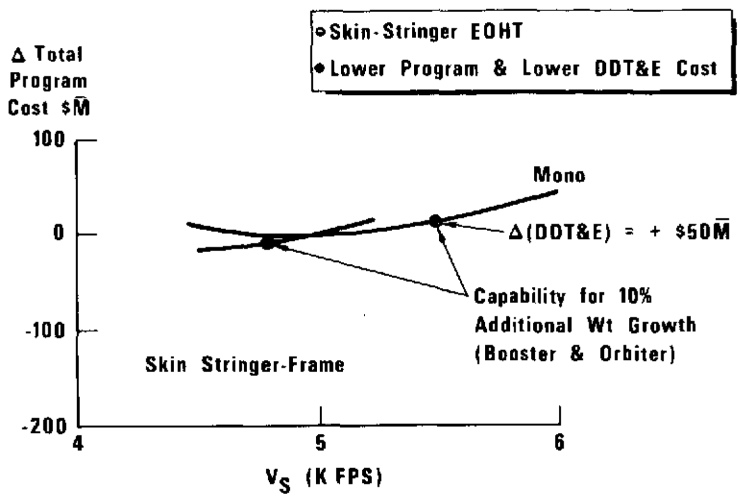
22SV18148C

A comparison was made to determine the relative cost for facilities to support each of the three programs. Also, an estimate was made of the total man-months required to support each program and, finally, an evaluation of the support equipment requirements for each program was made. It was seen that significantly less support equipment was required for the solid rocket motor systems, and that significantly fewer man-months were required to support design, development, test, and evaluation and the total program.



Variations of gross liftoff weight (GLOW), orbiter liftoff weight, empty external oxygen-hydrogen tank (EOHT) weight, and booster empty weight are plotted against staging velocity for two types of tank construction. Also shown on each curve is the design point selected to provide a 10-percent growth capability for both the booster and orbiter over the 10-percent initial margin design. A reduction in GLOW on the order of 600,000 pounds is obtained from switching from a monocoque to a skin-stringer tank. At the same time, a reduction in tank weight of approximately 11,000 pounds is obtained. Finally, booster empty weight is reduced approximately 100,000 pounds, which will be reflected in the design of the booster recovery system.

Impact of EOHT Design on Sys. Cost - PFB



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The impact on total program cost and the difference of design, development, test, and evaluation (DDT&E) costs for two different external oxygen-hydrogen tank (EOHT) designs is illustrated plotted versus staging velocity. It is seen that near the design points, where capability for 10 percent growth is available, the total program costs and the DDT&E costs are almost the same because the lower staging velocity available with the skin stringer frame tank construction will significantly simplify the difficulty of recovering the pressure-fed booster. The skin stringer construction for the EOHT was selected as the baseline for the pressure-fed booster (PFB) series-burn tandem arrangement system.

For both solid rocket motor (SRM) parallel-burn systems, the LH_2 tank is a lighter weight monocoque tank because the SRM thrust loads bypass the tank. The advantage of utilizing a skin stringer tank construction is therefore reduced to the extent that a monocoque tank was selected for both systems.

Weight Growth Approaches

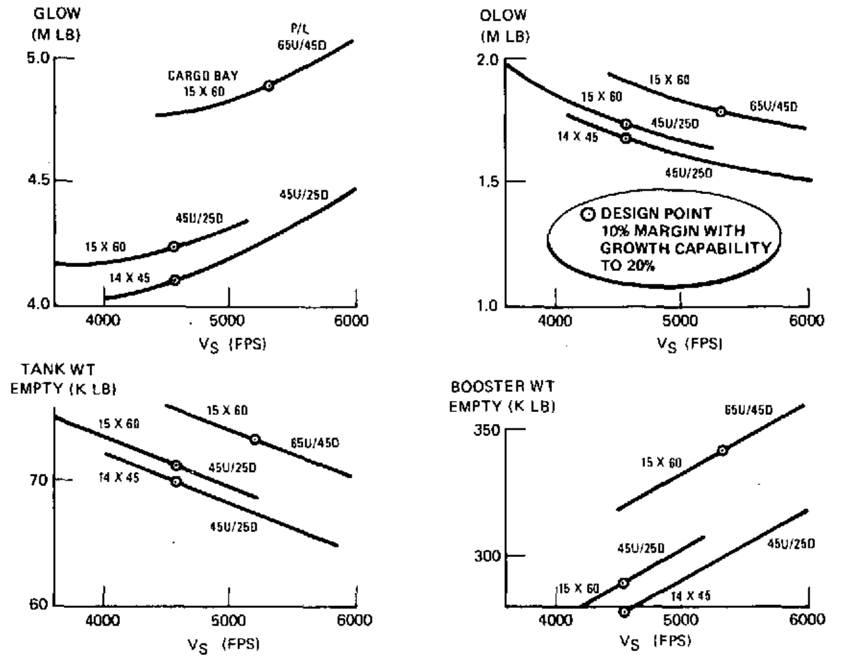
- **OVERSIZE INITIALLY FOR ALL EXPECTED WEIGHT GROWTH**
  - **Launch Partially Filled Tank Max Dynamic Pressure Constraint**
  - **Excess Payload Capability if Growth Fails to Develop**
- **NO GROWTH PROVISIONS**
  - **Expensive Redesign & Program Cost Escalation**
- **INITIAL 10% MARGIN WITH GROWTH CAPABILITY TO 20% BY OVERSIZING BOOSTER**
  - **If Growth Develops in Excess of 10% Resize Tank for Growth Up to 20%**

22SV17885A

Weight histories from various programs have indicated that we can expect up to a 20-percent increase from go-ahead through first flight. Three options are available to account for this anticipated gain. First, the design can be oversized for the entire 20-percent gain expected. If the weight increase failed to develop, extra payload capability would be available.

A second option would be to provide no growth provisions. This would result in redesign of the vehicle propellant tanks and perhaps an upgrading of the booster engine thrust, all of which would mean costly design changes and schedule slips. A third option would be to incorporate a 10-percent margin in the initial design and provide capability to grow another 10 percent by resizing the external oxygen-hydrogen tank (EOHT). It would be anticipated that initial sizing would take place at the preliminary requirements review and the weight growth during the design would be monitored through preliminary design review, at which time the EOHT would be resized to gain back at least a 10-percent margin.

Effect of Cargo Bay Size & Payload on System Parameters-156 in. SRM



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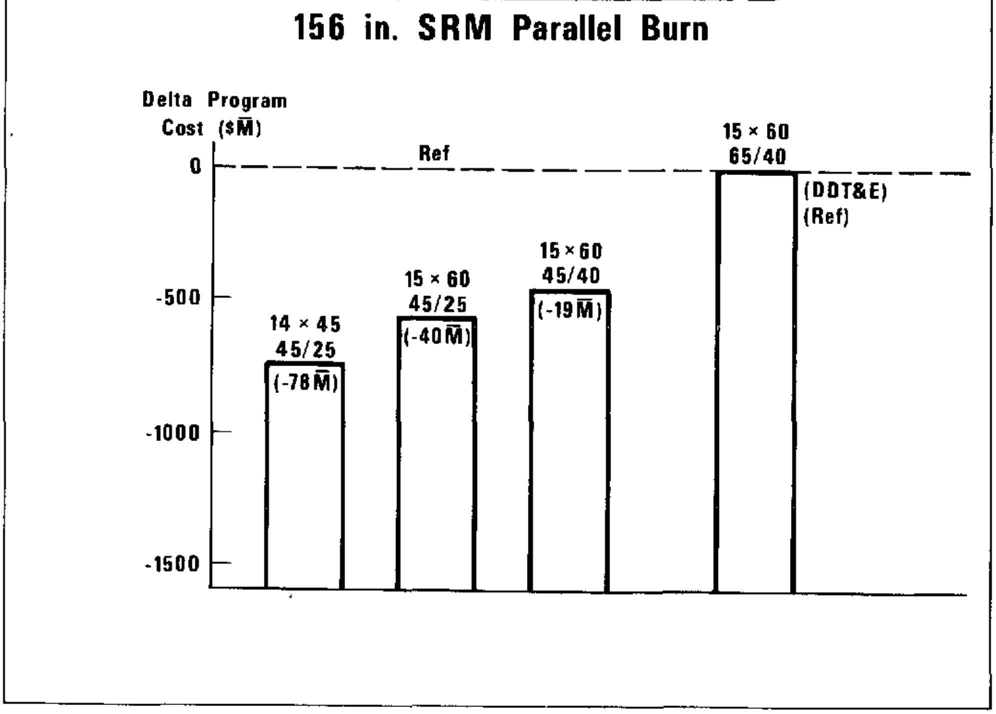
System parameters were calculated in terms of gross liftoff weight, orbiter liftoff weight, empty tank weight, and booster empty tank weight versus staging velocity for the orbiter and payload combinations under consideration. The trends for this system remain the same as those for the 120-inch parallel burn systems and the pressure-fed booster series burn systems in that the major weight savings accrued from changes in up payload. Similar results were determined for the other two systems.

Effects of Cargo Bay Size & P/L on Cost



Delta program costs were calculated for the system design points referenced to a baseline for a large cargo bay with full payload carrying capability. Again, approximately half the cost savings are accrued from reducing the up payload, the remainder being accrued from reduction in orbiter size and down payload.

Cost Driver Issues

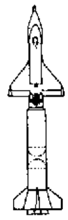
ISSUE	FINDINGS
• Impact of EOHT Mass Fraction (i.e., Monocoque VS Skin Stringer)	• Skin Stringer Frame for Series Burn Systems (PFB & SRM'S) (Lightweight Monocoque for Parallel Burn Systems (SRM'S)
• Weight Growth & Performance Sensitivity	• Not a Discriminator. All Systems Comparable
• Orbiter Payload & 14 x 45 FT Payload Bay Impact	• Major Cost Savings From Reduced Up-Payload, Secondary Savings From Reduced Down Payload & 14x45 Payload Bay

22SV18240A

It has been seen that reduction in orbiter payload and in payload bay size has the following impact on program costs: major cost savings from reduced up payloads, secondary savings from reduced down payloads and a smaller orbiter size.

Sys Size & Cost Summary-Liquid Fed Boosters

Orbiter
15 Ft × 60 Ft
(65U/40D)



Orbiter
14 Ft × 45 Ft
(45U/25D)

SERIES BURN RECOVERABLE PFB

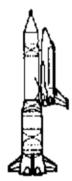
	15 × 60	14 × 45
GLOW (M Lb)	5.84	4.66
Prog Cost (B)	9.41	Δ -0.36
DDT&E Cost (B)	4.59	Δ -0.17
Cost/Flt ($\bar{M}$)	7.6	Δ -0.35

Orbiter
15 Ft × 60 Ft
(65U/40D)

PARALLEL BURN PFB

GLOW (M Lb)	6.56
Δ Prog Cost (B)	+0.79
Δ DDT&E Cost (B)	+0.03
Δ Cost/Flt ($\bar{M}$)	+0.3

Orbiter
15 Ft × 60 Ft
(65U/40D)



SERIES BURN RECOVERABLE F-1

GLOW (M Lb)	5.28
Δ Prog Cost (B)	-0.49
Δ DDT&E Cost (B)	-0.39
Δ Cost/Flt ($\bar{M}$)	-0.1

Note: Delta Costs Referenced to Series Burn Recoverable PFB, 15 × 60 Cargo Bay

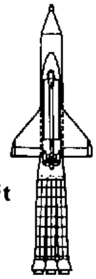
22SV182028

The gross liftoff weight (GLOW) and programmatic cost data are summarized as shown for the liquid-fed booster systems investigated in this study. The baseline system is the series-burn recoverable pressure-fed system with the 15- by 60-foot cargo bay (65 up/40 down payload requirement). All other costs are referenced to this baseline. The series-burn recoverable F-1 system shown has briefly been discussed previously in this report. Sizing of this system resulted in a gross liftoff weight (GLOW) of 5.28 million pounds with some savings in program cost; design, development, test, and evaluation (DDT&E) cost, and cost per flight compared with the baseline. For the liquid-fed recoverable systems, parallel burns result in somewhat higher GLOW's and higher costs. These increases are attributed to the poor mass fraction that results as the pressure-fed system decrease in size.

Sys Size & Cost Summary-SRM Boosters

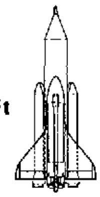
SERIES BURN 1207 SRM'S

Orbiter
15 Ft × 60 Ft
(65U/40D)



1207 PARALLEL BURN
(MONOCOQUE)

Orbiter
15 Ft × 60 Ft
(65U/40D)



Orbiter
14 Ft × 45 Ft
(45U/25D)

	6 SRM Skin-Str	7 SRM Mono
GLOW (M Lb)	5.43	6.11
Δ Prog Cost (B)	+3.79	+4.87
Δ DDT&E Cost (B)	-0.74	-0.86
Δ Cost/Flt($\bar{M}$)	+11.5	+13.8

	15 × 60		14 × 25
	5	6	4
GLOW (M Lb)	524	5.83	4.39
Δ Prog Cost (B)	+2.71	+3.78	+1.42
Δ DDT&E Cost (B)	-0.95	-0.89	-1.11
Δ Cost/Flt ($\bar{M}$)	+9.3	+11.6	+6.6

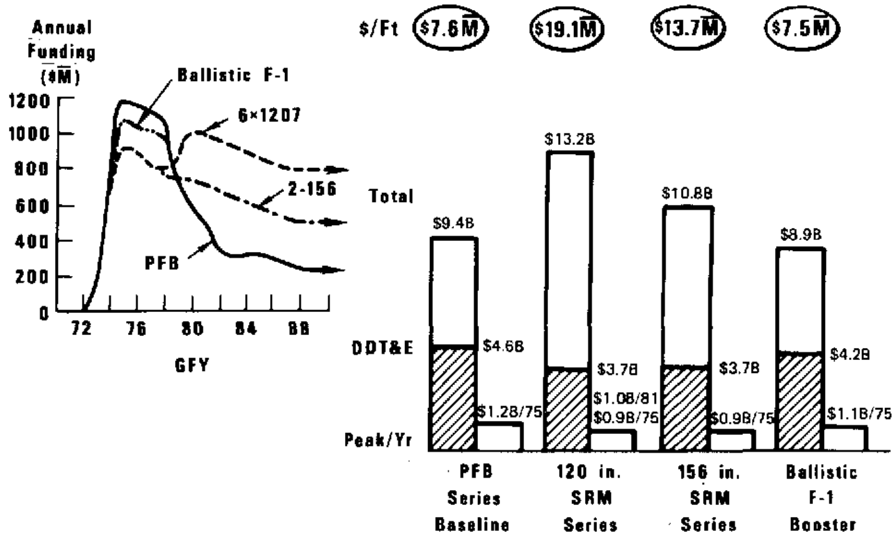
Note: Delta Costs Referenced to Series Burn
Recoverable PFB, 15 × 60 Cargo Bay

22SV18201B

As on the previous chart, all costs shown are referenced to a series-burn recoverable pressure-fed booster (PFB) 15- by 60-foot cargo bay system. Shown are the gross liftoff weights (GLOW's) and programmatic costs for the series-burn 1207 solid rocket motors (SRM's) and the parallel-burn 1207 SRM's. As shown previously, the program costs for the SRM's and the cost per flight are substantially higher than for the liquid-fed systems. The design, development, test, and evaluation (DDT&E) costs, however, are significantly lower. These conclusions also apply to the 156-inch SRM systems.

Cost Comparison - Series Boosters

15 Ft x 60 Ft Cargo Bay Size

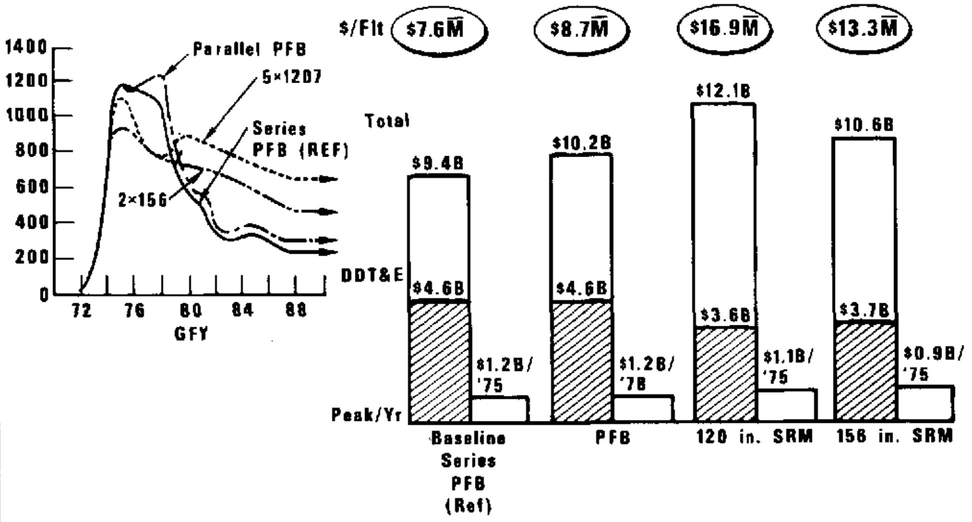


22SV17837C

Program funding requirements and cost comparisons for the series systems are shown. The liquid pressure-fed booster (PFB) 120-inch solid rocket motor (SRM), 156-inch SRM, and ballistic F-1 booster systems are compared. It is seen immediately that the liquid feed systems have the lowest cost per flight and the lowest program costs. The 120-inch SRM's have the highest cost per flight and no particular advantage over the 156-inch systems in other cost categories. Therefore, the 120-inch series system should be dropped from further consideration. The ballistic F-1 booster is attractive compared to the PFB series system. However, little design analysis is available at this time to substantiate the cost figures. Nevertheless, the system is attractive enough to warrant further investigation. The two attractive systems, then, from this comparison are the PFB series baseline and the 156-inch SRM system.

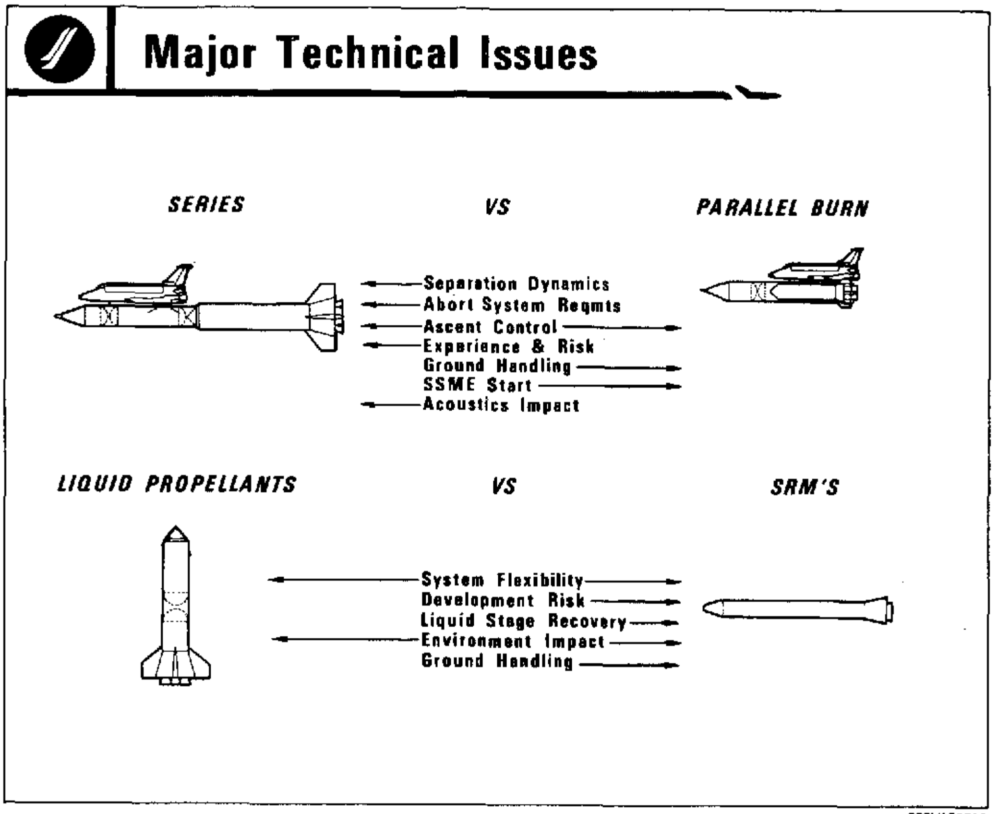
Cost Comparison - Parallel Boosters

15 Ft x 60 Ft Cargo Bay Size



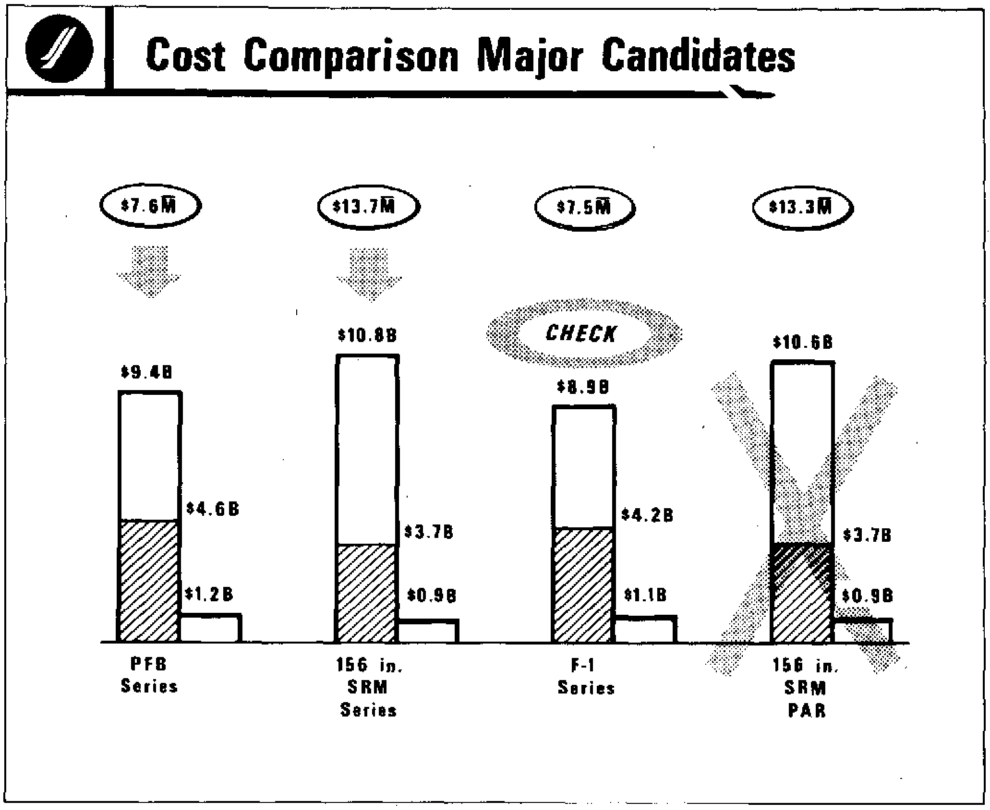
22SV17938C

Programmatic costs have been computed and are compared for the parallel systems considered in this study. Again, it is seen on a cost per flight basis that the SRM systems are much more expensive than the liquid-fed systems. Of the two parallel SRM booster systems, the 156-inch system is the more attractive and likewise is more attractive than the parallel-burn PFB because of its lower design, development, test, and evaluation cost. Therefore, of the three parallel systems considered, the 156-inch system should be retained for further comparison. The PFB parallel-burn system has no advantage over the series-burn system and it should therefore be deleted from further consideration.



22SV18253C

A summary of the major technical issues described in this report is presented on the associated chart. It has been shown that the separation dynamics related to the series system are significantly more straightforward than for the parallel-burn system. Likewise, the requirements for implementing the abort system in terms of SRM boost are simpler because of the lack of thrust vector control (TVC) requirement on the abort solid rocket motors. Ascent control requirements for both systems are approximately the same. However, the key issue of whether TVC is required on the booster motors in the parallel-burn system has been resolved as follows: unless significant impact to the orbiter is accepted, booster TVC is required for the parallel-burn systems. Experience and relative risk are in favor of the series systems because of a long history of successful series-burn launch vehicles. The parallel-burn system appears to have some advantages in ground handling because of its closeness to the ground. Some advantage is seen for the parallel-burn system in start of the space shuttle main engine motors on the ground — assurance that these engines are started and running stably before liftoff. With regard to acoustics, no significant difference between impact on the ground is seen between the two but the parallel burn system shows a higher impact than the series burn system. It is felt that the liquid propellant system is more flexible than the SRM's because of the ability to tailor the thrust time history at almost any point in the program. However, the development risk appears to be in favor the SRM's because of their greater simplicity. It is felt that recovery of the liquid-fed booster constitutes a significant program risk. Neither system has significant impact on the ground environment. Ground handling for the SRM's appears to be more simple than for the liquid propellant systems. Based on technical merit, it is recommended that the accepted system incorporate a series-burn mode utilizing solid propellant motors.



22SV18241A

Shown on the chart are programmatic cost comparisons for the most attractive of the systems considered. In a comparison of the 156-inch systems, the parallel-burn system has not significant advantage over the series-burn system and the series-burn system is preferred technically. Therefore, it is recommended that the 156-inch solid rocket motor parallel-burn system be dropped from consideration. The F-1 series burn recoverable boost system is attractive but further investigation is needed to verify the technical merits of this system and cost predictions. Finally, the pressure-fed booster series-burn system compared to the 156-inch SRM series-burn system has significantly lower cost per flight and programmatic cost; however, its design, development, test, and evaluation peak annual funding exceeds that of the 156-inch solid rocket motor series-burn system.

Conclusions

- Series Comparable Cost to Parallel & Less Risk
- SRM'S Lower Devel Risk
- Liquid Boosters Best Meet all Cost Goals
- 15 x 60 Orbiter Best
- If Minimum Development Risk and/or Cost is the Major Criteria-Choose Series-Solid
- If Meeting All Cost Goals is the Major Criteria -Choose Series-Liquid

225V18256B

The conclusions of this study are shown on the chart. The series-burn system is comparable in cost to the parallel-burn systems and has less risk from a technical viewpoint. Also, it is felt that the solid rocket motor development program entails less risk than that of the pressure-fed booster system. The cost of both the solid- and liquid-fed systems compared to the program cost goals illustrates that the liquid systems best meet all the goals, although they do exceed slightly the design, development, test, and evaluation and peak annual funding limitations. It was seen that a major cost savings could be accrued with a reduction in the up payload. However, little advantage was gained by reducing the payload bay size or the down payload. Therefore, it is recommended that the 15- by 60-foot cargo bay orbiter be retained as the baseline. Finally, if minimum development risk and cost are the major criteria for program selection, then a series-burn configuration utilizing solid propellant boosters should be selected. But if closely approximating all the cost goals is a major criterion, then a series-burn system with liquid propellants should be the selected option.